Graph-based Multi-Objective Generation of Customised Wiring Harnesses

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ABSTRACT

Electrical wires are a very important part of a vehicle as well of many other objects with electrical functions. These wires are summed up to harnesses. Engineers often manually create the virtual paths for wires by considering their expert knowledge. More variants of a product often require different wires and the criteria for cables do vary. Criteria, e.g. heat or the length, define the wire path and configuration and have to be taken into account. Engineers may not be able to consider all criteria, notably when there is an extensive amount of product variants, or when the object configuration is changing. This paper will evaluate if a multi-objective evolutionary algorithm can compute feasible wire paths where two of these criteria are optimised. We are showing that discretised free-space in a graph structure enables an evolutionary algorithm to compute wire suggestions by using customised reproduction operators for path planning. The developed crossover and mutation operators are suitable for multi-objective path finding, may be used in other fields as well and will be extended in future research.

CCS CONCEPTS

• **Theory of computation → Evolutionary algorithms**; • **Applied computing → Computer-aided design**; *Electronics*;

KEYWORDS

Evolutionary algorithms, customization, wiring harness, automotive industry, customisation

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1 INTRODUCTION

In the recent years, automotives are becoming more and more electrical. Adding a new a new sensor or system means more linkage by wires to ensure communication through the whole vehicle. Wires are often constructed with a high manual approach, only with the engineers' knowledge. Electrical wires run through several zones in a vehicle, where they face moist, heat, vibration and other circumstances. In future autonomous cars, a self-rewiring harness has to evaluate all of these criteria in order to find a feasible and cost effective path. The amount of existing criteria is not only from a physical nature but also design questions are extending the number. For instance, customers of vehicles do not want to see wires, hence the path of a wire through an object should be invisible to a customer. On the other side, wires should be positioned in the areas with less heat and damage probabilities. Considering all these criteria, in this paper we present a multi-objective approach to generate wires by using the NSGA-II algorithm for pathfinding and optimising length and temperature. For demonstration purposes we chose two fixed parts between a feasible one-wire cable configuration is calculated.

The cable harness routing problem (CHRP) was defined by Conru, who used a genetic algorithm in order to find an optimal cable harness configuration by optimising one objective [2]. Hermansson et al. proposed a method to calculate wire paths with respect to certain constraints by using a resolution complete A^* based grid search and tested the feasibility of wires by using a simulation based on the *Cosserat rod theory* [4]. Wiring harness generation is a complex task, since engineers have to take an extensive amount of conditions into account. Not only they must have information about wire hazardous zones, e.g. areas with high temperatures or moisture but also they should consider the cost of the material and preferably reduce them. In reality, they often *know* where those zones are and can construct the wires accordingly into 3-D space.

2 GRAPH-BASED SEARCH DOMAIN

In order to find wire paths inside an object, a structure is required which represents all relevant information. The state-of-the-art methods use graphs such as proposed by [1, 5, 6]. The so called *vehicle graph* proposed by Weise et al. [6], represents each part of an object as a node and the fasteners as edges in a graph. They additionally extended the graph by representing the "free space".

2.1 Free Space Discretisation

To discretise the free space in the vehicle, we are evaluating two approaches. At first we use a methodology to create 3-D cubes in the geometry, perform a clearance analysis and subtract all cubes with clearance violations. All remaining cubes represent *the negative* of the vehicle, hence the free space. Every cube is represented by a node in the graph and each of them is connected to its 6 neighbours

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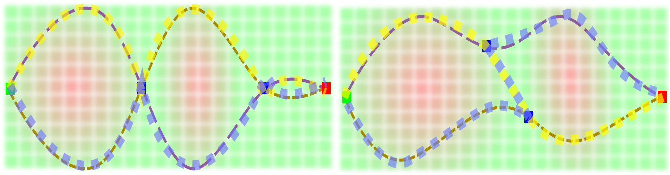

Figure 1: Crossover operator

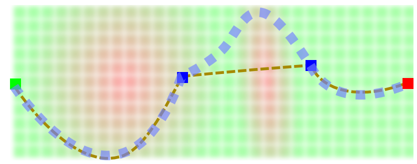

Figure 2: Mutation operator

(one per side). Furthermore, the cubes' real part neighbours are identified and connected by an edge.

The second, more complex method is a discretisation by using tools and methods from the computational fluid dynamics field. To perform this, we use tools from the *OpenFOAM* framework. The mesh creation and graph generation afterwards are more complex due to the large amount of generated cubes and different neighbourhood relationships. We use the first method for a proof-of-concept and will evaluate the more precise method in further research.

We use the proposed graph-property-model and extended the labels by the type *free space* and for the relationship types we also introduce a *free space* type. Due to the new types we can reduce the search space for path finding by only using nodes and relationships from the free-space domain and the respecting part-neighbours, without altering the whole graph structure.

2.2 Multi-objective path finding

The most trivial criteria for optimizing a wire's geometry is the length which also describes how much material is used and is proportional to its costs. The second criteria is the wire's average temperature. Other criteria might be the wire's diameter, cable cores, transferred information density or moisture. Some of them can be obtained by simulation. For the evaluation of our approach we create an example for the field of heat as shown in figures 1 and 2. The high temperature spots are shown in red while it decreases with increasing distance. The high spots mark a source of heat.

In the following we consider two objectives, the length and average temperature and modify the well-known NSGA-II algorithm [3] to solve this specific application. Here, we do not have a fixed length variable vector representing a chromosome. Therefore, we take a path as a chromosome and develop customised crossover and mutation operators with altering sub-paths.

For crossover operator, we consider two cases: 1) two paths have common way points and 2) there is no common point. In the first case, we perform a 2-point cross-over. In the other case, an arbitrary point from each path is taken, the Dijkstra's shortest path between them is calculated and the resulting path is built. For both cases the starting paths are alternated between the two parents to have two offspring chromosomes. Figure 1 depicts the operator. The left figure shows the first case the right one depicts the second case. The thick blue and yellow paths are the offspring of the thin parents.

The mutation operator on a path, is implemented by choosing two points from a path with a maximum distance of 100 and perform Dijkstra's algorithm to find an optimal sub-path with respect to the temperature. If the chromosomes length is under 100, the whole length is the maximum distance. Figure 2 illustrates the operator. The two blue squares represent the random points in-between a sub-path is calculated. The figure shows the single objective optimisation of the temperature objective, where the blue (mutated sub-path) is colder but longer then the original parental path.

3 EXPERIMENTS AND RESULTS

We chose an initial set of 200 randomly generated solutions by performing a Monte-Carlo-Search in the *free-space-domain* of the graph. As the starting point we chose the light switch and calculated a wire to the left front light. We run the algorithm for 300 generations. The crossover and mutation operators are applied with a probability of 80% and 15%, respectively. The experiment resulted in a generated non-dominated front representing several cable configurations from which an engineer can decide or elaborate on which cable to construct. Several fairly cold generated cables had highly amounts of turns in the colder regions of the free-space-domain, resulting in very low average temperature. The mean hypervolume is 0.9980 and standard variance $1.4584 \cdot 10^{-6}$ after 300 generations considering a normalised hypervolume, hence the non-dominated front over all evaluations has a hypervolume of 1.

4 CONCLUSION

In this first proof-of-concept we showed the feasibility of multi-objective wire generation by using NSGA-II for path planning problems, namely the cable harness routing problem (CHRP). We developed customised use-case orientated crossover and mutation operators and evaluated the approach for a small example. The results show, that the algorithm can find feasible wire paths and can give suggestions to an electrical engineer. In further research we will enlarge and refine the search space and will evaluate the multi-objective generation of whole wire harnesses by extending the proposed operators.

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